1911

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

A PRELIMINARY INVESTIGATION TO DETERMINE THE SAFETY AND ECONOMIC BENEFITS OF WATER-FILLED TUBE BARRIERS

HOUSE RESOLUTION NO. 203

1968 LEGISLATIVE SESSION

MARCH 1969

68-51

68-51

STATE OF CALIFORNIA | RONALD REAGAN, Governor

BUSINESS AND TRANSPORTATION AGENCY

1120 N STREET, P.O. BOX 1139, SACRAMENTO 95805

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SAVINGS AND LOAN

GORDON C. LUCE
Secretary
MARC SANDSTROM
Assistant Secretary
MERRITT E. VAN SANT
Assistant Secretary

March 30, 1969

Hon. James D. Driscoll
Chief Clerk of the Assembly
State Capitol
Sacramento, California

Dear Mr. Driscoll:

Pursuant to the provisions of House Resolution No. 203 (Bear - 1968), I am transmitting a report entitled "A Preliminary Investigation to Determine the Safety and Economic Benefits of Water-filled Tube Barriers."

Sincerely,

GORDON C. LUCE, Secretary of
Business and Transportation

Attachment

cc: Hon. Ronald Reagan, Governor
Mr. Vernon J. Cristina
Mr. Robert E. Herdman
Mr. Fred C. Jennings
Mr. Moon Lim Lee
Mr. Alexander H. Pope
Mr. V. Earl Roberts
Mr. William S. Whitehurst

SIMILAR LETTER SENT TO:

Hon. C. D. Alexander
Hon. Alan Short
Hon. John F. Foran

Mr. James A. Moe
Mr. H. S. Fenton
Mr. E. W. Rhyner
Mr. J. A. Legarra
Mr. Sam Helwer
Mr. D. L. Wieman
Mr. J. T. Kassel
Mr. R. T. Martin
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March 30, 1969

Hon. John F. Foran, Chairman
Assembly Transportation Committee
State Capitol
Sacramento, California

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March 30, 1969

Hon. C. D. Alexander
Secretary of the Senate
State Capitol
Sacramento, California

Dear Mr. Alexander:

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Assistant Secretary

MERRITT E. VAN SANT
Assistant Secretary

March 30, 1969

Hon. Alan Short, Chairman
Senate Transportation Committee
State Capitol
Sacramento, California

Dear Alan:

Pursuant to the provisions of House Resolution No. 203 (Bear-1968), I am transmitting a report entitled "A Preliminary Investigation to Determine the Safety and Economic Benefits of Water-Filled Tube Barriers."

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March 30, 1969

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Secretary of the Senate
State Capitol
Sacramento, California

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Sincerely,

Gordon C. Luce

GORDON C. LUCE, Secretary of
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Sincerely,

Gordon C. Luce

GORDON C. LUCE, Secretary of
Business and Transportation

Attachment

TABLE OF CONTENTS

1968 Legislative Session

HOUSE RESOLUTION NO. 203

Relating to Water-Filled Safety Devices for Vehicles and Freeways

Resolved by the Assembly of the State of California, that the Transportation Agency, in cooperation with the Department of General Services, is requested to conduct an investigation concerning the safety and economic benefits of water-filled bumpers for vehicles and water-filled barriers for obstacles adjacent to freeways, with reference to be made, to the greatest extent possible, to research efforts being done by other agencies concerning these subjects; and be it further Resolved, That the Transportation Agency, in cooperation with the Department of General Services, is requested to prepare and submit a preliminary report to the Legislature no later than March 30, 1969, concerning the results of the investigation conducted, including in its report the feasibility of putting water-filled bumpers on State-owned vehicles.

[illegible] water-filled structures [illegible]

[illegible] will be made [illegible]

[illegible] efforts being [illegible]

[illegible] concerning these suggestions and/or [illegible]

[illegible] the Transportation Agency in conjunction [illegible]

Department of General Services, [illegible]

[illegible] a preliminary report to the Legislature [illegible]

[illegible] 10, 1962, concerning the results of the [illegible]

[illegible] including in such report [illegible]

I. INTRODUCTION

During the 1968 session of the Legislature, the Assembly passed House Resolution No. 203. This resolution requested, in part, that the Transportation Agency conduct an investigation concerning the safety and economic benefits of water-filled tube barriers for obstacles adjacent to freeways. Reference was to be made, to the greatest extent possible, to research efforts accomplished by other agencies. Consequently, this report considers the results of all the research on water-filled tubes accomplished to date by the manufacturer, John Rich Enterprises, Incorporated, of Sacramento, California; Brigham Young University; and the Materials and Research Department of the California Division of Highways.

In 1967 the Division of Highways initiated a research project to find an effective energy absorbing system. As a part of this project, full scale testing of a barrier incorporating water-filled tubes was performed. This research project was started because of concern about the increasing incidence and the relative severity of accidents involving errant vehicles impacting fixed objects located adjacent to the roadway.

The following criteria were tentatively established to judge the effectiveness and feasibility of various energy absorbing barrier designs. Effective energy absorbing barriers should impart tolerable decelerations to an impacting vehicle. When head-on impact into the barrier occurs at 60 mph or less, the vehicle should be stopped without sustaining an average decelerating force (highest 40 milliseconds) of more than 12 G's. An energy absorbing barrier should be at least as effective as California's current anchored "W" beam guardrail in redirecting a vehicle that collides at an oblique angle with the side of the barrier. Initial construction costs and maintenance costs should be kept to a minimum consistent with safety and aesthetic requirements. Because of the hazards caused by maintenance, the damage to the barrier and the time required to repair it should be kept to a minimum. The barrier should also be designed such that no parts will be dislodged and ejected into the traveled way upon impact.

The water-filled tube concept consists of absorbing energy through the lateral and vertical displacement of a containerized mass of water. Initial developmental work on this concept by the developer and subsequent tests at Brigham Young University indicated that a barrier incorporating this method of energy absorption could be designed to satisfy the aforementioned tentative criteria.

Although many different energy absorbing barrier concepts were considered, the water-filled tube concept was the most promising concept that was not already the subject of an exhaustive research effort by this or other research groups at that time. Consequently, the Division of Highways contacted the manufacturer, John Rich Enterprises, Incorporated, of Sacramento, in the fall of 1967 and plans were made for a series of full scale tests on barrier designs that incorporated the water-filled tube concept. Numerous discussions were held with members of the manufacturer's engineering staff during the development and testing of the barrier. The results of four tests conducted by the Division of Highways to date are summarized in the Appendix of this report and comments are offered in the discussion portion of this report.

This report also discusses further developmental tests performed by the manufacturer that began in the fall of 1968 and future tests planned by the Division of Highways for the late spring and summer of 1969.

II. OBJECTIVE

The objective of this study, in response to House Resolution No. 203, was to conduct an investigation of the safety and economic benefits of water-filled tube barriers for obstacles adjacent to freeways, with reference made, to the greatest extent possible, to research efforts by other agencies.

III. CONCLUSIONS

The water-filled plastic tube barrier concept has a very good possibility of fulfilling the safety and economic requirements of an effective energy absorbing barrier. It appears that a significant reduction in accident severity may be effected through the use of this system at vulnerable highway fixed object locations. However, further testing, now scheduled by the Division of Highways for the late spring and summer months of 1969, must be completed before an accurate appraisal of the safety aspects of this concept can be made. Operational experience from a limited number of trial installations would then be required to fully assess the economic benefits that might be realized by the adoption of this concept for use on freeways in California.

IV. DISCUSSION

The initial full-scale developmental tests of energy absorbing water-filled tubes were conducted by the manufacturer, John Rich Enterprises, Incorporated, starting in 1966. Subsequent testing has been accomplished by Brigham Young University under contract to the manufacturer, by the California Division of Highways, and then again by the manufacturer. These tests are discussed below.

A. Initial Tests by the Manufacturer

The first full-scale developmental testing of the water-filled tube concept was accomplished by the manufacturer. This consisted of low speed tests (less than 30 mph) using a live driver and minimal photographic coverage. These tests were performed to ascertain the feasibility of absorbing the kinetic energy of an errant vehicle with the horizontal and vertical displacement of a containerized mass of water. The results of these tests indicated to the manufacturer that a more detailed series of full-scale tests was warranted.

B. Tests by Brigham Young University

A series of 40 full-scale impact tests into barriers composed of water-filled tubes was conducted and the results were analyzed by the Department of Mechanical Engineering, Brigham Young University, in 1967 under contract to the manufacturer[1]. This BYU testing was conducted in two phases and was accomplished to evaluate the water-filled tube concept and to develop design information for the water-filled tube barrier. The water-filled tubes tested were 40 inch long, 6 inch outside diameter vinyl plastic cylinders with integrally formed bottoms. The tops were attached to the tubes with bolts. Holes were drilled in the tops through which water was ejected when the barrier was impacted. Tube clusters in widths varying 2'-6" to 4'-0" and lengths varying from 2'-6" to 9'-0" were tested by vehicle impact. Deceleration was determined using electronic and/or photographic techniques.

A modified 1961 3/4 ton pickup truck was used as the test vehicle in the Phase I tests. Vehicular control was provided by a live driver. Impact was head-on into the end of the barriers at speeds from 5 mph to 35 mph. Phase I constituted a total of 36 tests. Because of the maximum speed limitation with live drivers and the lack of representative vehicular energy absorption by the modified test vehicle, four additional tests, designated as Phase II by the BYU researchers, were conducted using stock passenger automobiles and remote control of the test vehicles.

The Phase II tests were also conducted head-on into the barrier. The impact speeds were 44, 45, and 59 mph. A 45 mph test was also conducted into a rigid timber backstop to simulate impact into an unprotected fixed object and to obtain comparative data.

The BYU researchers concluded, based on the results of their testing, that "in principle, a properly designed hydraulic-plastic cushion unit" is fully capable of providing "satisfactory impact energy attenuation" for standard automobile impacts at speeds up to 60 mph. It was also stated that a 50% decrease in property damage would be realized if protection from fixed objects is provided with water-filled tubes. Several design recommendations were made with regard to the individual tubes and to the over-all barrier configuration and construction.

It is significant to note that all of the BYU tests were head-on collisions. Freeway accident data indicates that many errant vehicles strike fixed objects at oblique angles of 15° or more with the roadway centerline.

C. Tests by the California Division of Highways

The results of the previous testing by the manufacturer and by Brigham Young University were generally favorable although certain characteristics appeared to be in need of improvement, some of which were noted in the BYU report[1]. Consequently, after discussions with the engineering staff of the manufacturer late in 1967 and early in 1968, the water-filled tube barrier was chosen by the Division of Highways to be subjected to the first series of full-scale impact tests conducted under its ongoing research project on energy absorbing barriers. In an effort to make more efficient use of the water-filled tubes and, consequently, decrease the total cost of the barrier, a composite design, consisting of timber diaphragms placed betw[illegible] small clusters of the plastic tubes, was developed in cooperati[illegible] with the manufacturer and was tested. Retired California Highway Patrol vehicles (1966 sedans) were used as test vehicl[illegible] An instrumented 200 pound anthropometric dummy was placed in t[illegible] driver's seat for all tests. The test vehicle was remotely controlled from another vehicle using radio signals. A total of four full-scale tests was conducted by the Division of Hi[illegible] in the summer of 1968 on barriers incorporating the water-fil[illegible] tube concept.

Exhibit 1 contains photographs of the barriers tested. The barrier was modified for the third test and again for the f[illegible] test. Comments on these four tests are as follows:

Test No. 211. See Exhibit 2 for a summary of the test resul[illegible] This first test was conducted at 15 mph head-on into the barrier to observe the interaction of the barrier com[illegible] when subjected to low-speed impacts. The barrier was 5' wide at the nose, 8'-0" wide at the rear, and 15'-0" l[illegible]

Vehicular deceleration was relatively smooth. The maximum penetration of the test vehicle into the barrier was 5 feet. The final post impact position of the leading edge of the barrier was 4'-1" behind its original, pre-impact location. There was a slight rise (2 inches) imparted to the front of the vehicle immediately after impact.

No damage was sustained by either the vehicle or the barrier. No injury producing forces were sustained by the dummy. The steering wheel of the test vehicle sustained no permanent deformation.

Test No. 212. See Exhibit 3 for a summary of the test results. This second test was conducted to observe the impact severity when the barrier was struck head-on at a speed of approximately 30 mph. The same barrier employed on the previous test was used for this test.

Deceleration was not as smooth as that experienced during the 15 mph test. The maximum vehicular penetration into the barrier was 8'-4". The post-impact position of the leading edge of the barrier was 6'-6" behind its original, pre-impact location. The front of the test vehicle rose 9" during the collision.

Although the damage sustained by the barrier was considered minor, the vehicular damage was moderate (see Exhibit 6). The unrestrained dummy, located in the driver's seat of the vehicle, struck the steering wheel with sufficient force to impart a permanent deformation of 2-1/4" thereto (see Exhibit 7).

Test No. 213. See Exhibit 4 for a summary of the test results. This third test was conducted to determine the barrier's effectiveness when impacted head-on at a speed of approximately 50 mph. The barrier used for the earlier tests (211 and 212) was modified for this test. The shape of the barrier nose was changed, some of the tubes were replaced with tubes containing water in only their upper half, and the number of orifices in the tubes in the rear of the barrier was increased. The barrier nose was 6 inches wide. These modifications were mutually agreed upon by researchers from the manufacturer and the State. The rear of the barrier remained 8'-0" wide and the length was increased to 16'-5".

Deceleration was more severe than that observed during the 30 mph test (212). The maximum vehicular penetration into the barrier was 12'-5". The post-impact position of the leading edge of the barrier was 6'-2" behind its original pre-impact location. The vehicle rose 11 inches and rode up on the barrier nose. This vehicular rise accounts for the large difference between total vehicular penetration and barrier displacement.

Minor barrier damage was again sustained. Vehicular damage, however, was considered severe (see Exhibit 6). The dummy, restrained for this test with both a lap belt and a single diagonal shoulder harness, again struck the steering wheel and imparted a permanent deformation of 2-1/2" thereto (see Exhibit 7).

Test No. 214. See Exhibit 5 for a summary of the test results. Because of the characteristics observed in vehicular damage sustained during Test 213, additional barrier alterations were mutually agreed upon and accomplished before the fourth test was conducted head-on at an impact speed of 60 mph. The three leading diaphragms were replaced with lighter, stronger structures and small diaphragms were inserted between the tubes located between the two leading diaphragms. The barrier nose was 2'-0" wide and the rear remained 8'-0" wide. The over-all barrier length was 16'-2".

Deceleration was fairly smooth until the barrier "bottomed out". The vehicle then twisted longitudinally and the front end rose more than 6 ft. as the nose of the barrier was doubled back on the body of the barrier. Much of the vehicular rise took place after the cable that provided vertical and lateral restraint forthe barrier came loose at the front anchor. The maximum vehicular penetration was 13'-8". The post-impact position of the leading edge of the barrier was only 3'-2" behind its original, pre-impact location. The displacement of the barrier, up and back as the vehicular rise took place, accounts for the large difference between the vehicular penetration and the displacement of the barrier nose.

The barrier damage sustained for this test was moderate, but the vehicular damage was very severe (see Exhibit 6). The dummy, again restrained with both a lap belt and a single diagonal shoulder harness, impacted the steering wheel with sufficient force to impact a permanent deformation of 3-3/4" to it (see Exhibit 7).

The barrier performance during the second, third, and fourth tests by the Division of Highways was much less favorable than anticipated or desired. Consequently, it was decided that any further testing would be contingent on the results of a comprehensive analysis of the data obtained from these four completed tests. Although no full-scale tests were conducted at oblique angles with the side or nose of the barrier, they were planned and are still judged necessary before a complete evaluation of the effectiveness of this barrier can be made.

D. Recent Tests by the Manufacturer

While analysis of the Division of Highways' tests was in progress, the manufacturer of the plastic water-filled tubes established a test site near Sacramento and began a series of full-scale developmental tests on composite barriers incorporating their water-filled tubes. This test series by the manufacturer, begun in the fall of 1968, has consisted of more than 26 tests to date and is still in progress. Ten of these tests were conducted with impact on the side of the barrier and the remainder with impact into the barrier nose, either at a 10° angle with the barrier axis or on the barrier axis. Representatives of the Division of Highways were invited to, and did witness, many of these recent tests. Although the instrumentation utilized for this testing was not as sophisticated as that used in the Division of Highways' tests, the over-all performance of the barrier could be appraised with a fair degree of accuracy. As the manufacturer's test series has progressed, it has been apparent that many of the barrier deficiencies noted during the four Division of Highways' tests and during the current tests are being progressively corrected. Definite dynamic response and economic improvements are being incorporated into the designs and are being tested by the manufacturer.

E. Future Testing

It now appears that, based on the observations of the manufacturer's recent tests, additional testing of the water-filled tube barrier is warranted by the Division of Highways. Both head-on and oblique angle impacts utilizing the relatively heavy retired CHP sedans are planned. A new test barrier that incorporates all the desirable features developed and tested to date is currently being designed by the manufacturer. This revised barrier will likely provide satisfactory energy absorbing capabilities for both head-on and oblique angle impacts. These additional tests by the Division of Highways will be started in May 1969.

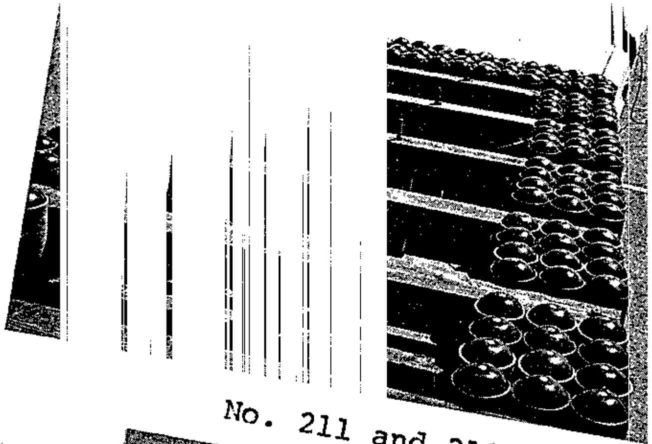
F. Summary

The results of the initial developmental tests of the water-filled tube concept by the manufacturer and by Brigham Young University indicated that a barrier incorporating this feature could satisfy the criteria used to define an effective energy absorbing system. However, the results of a series of four tests conducted by the Division of Highways were less favorable than anticipated or desired. Recent testing of design modifications by the manufacturer have, based on observations of this testing, resulted in an improved barrier design. Consequently, further testing of the water-filled tube concept by the Division of Highways, in cooperation with the Bureau of Public Roads, is now scheduled for the late spring and summer months of 1969. The over-all feasibility of adopting this concept for California's freeways from a safety standpoint is contingent on the results of these approaching tests, plus considerable research now in progress on other energy absorbing concepts by other agencies. If the results of the testing indicate that barriers incorporating the water-filled tube concept can safely decelerate and redirect an errant vehicle, trial installations will be recommended. The relative economic benefits that might be realized with the use of this concept will then become apparent.

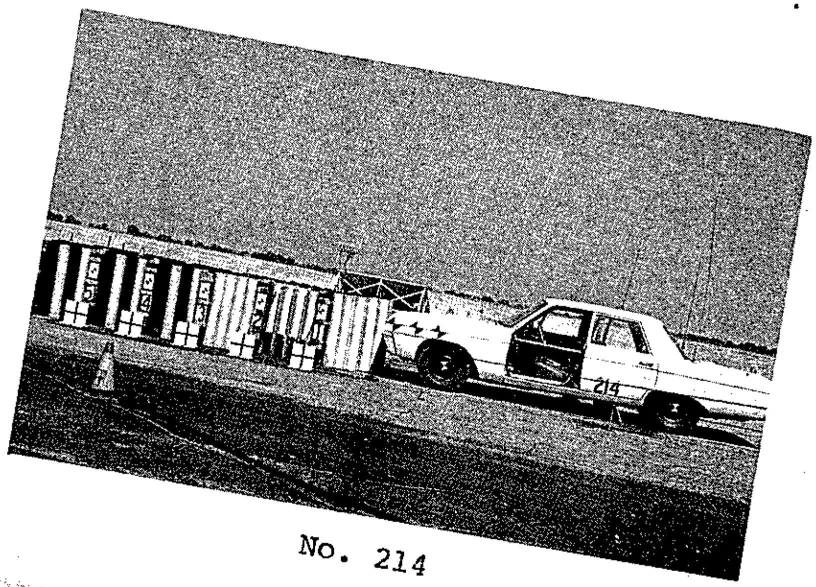
V. REFERENCES

1. Engineering Evaluation of Water-Filled Plastic Cells in Fixed Barrier Automobile Impacts, Report No. RSCB-2, Brigham Young University Department of Mechanical Engineering, January 5, 1968.

Exhibit 1



No. 211 and 212



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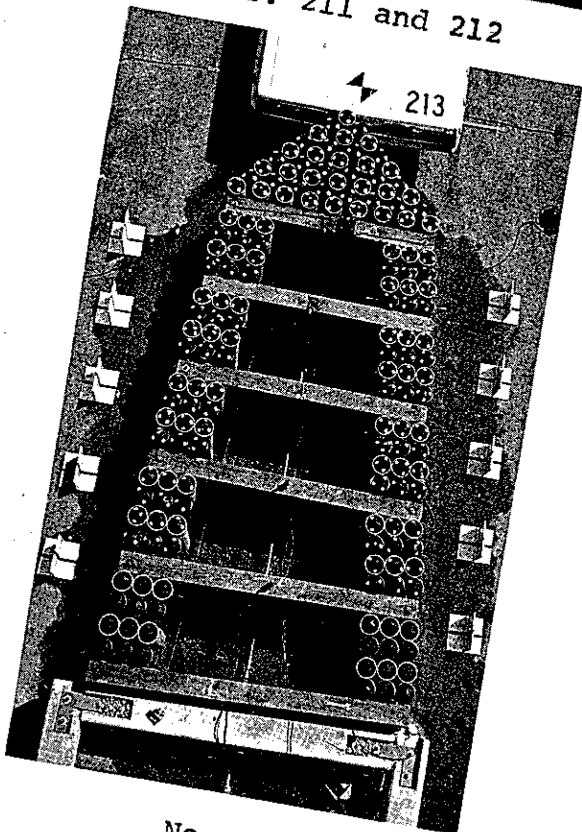

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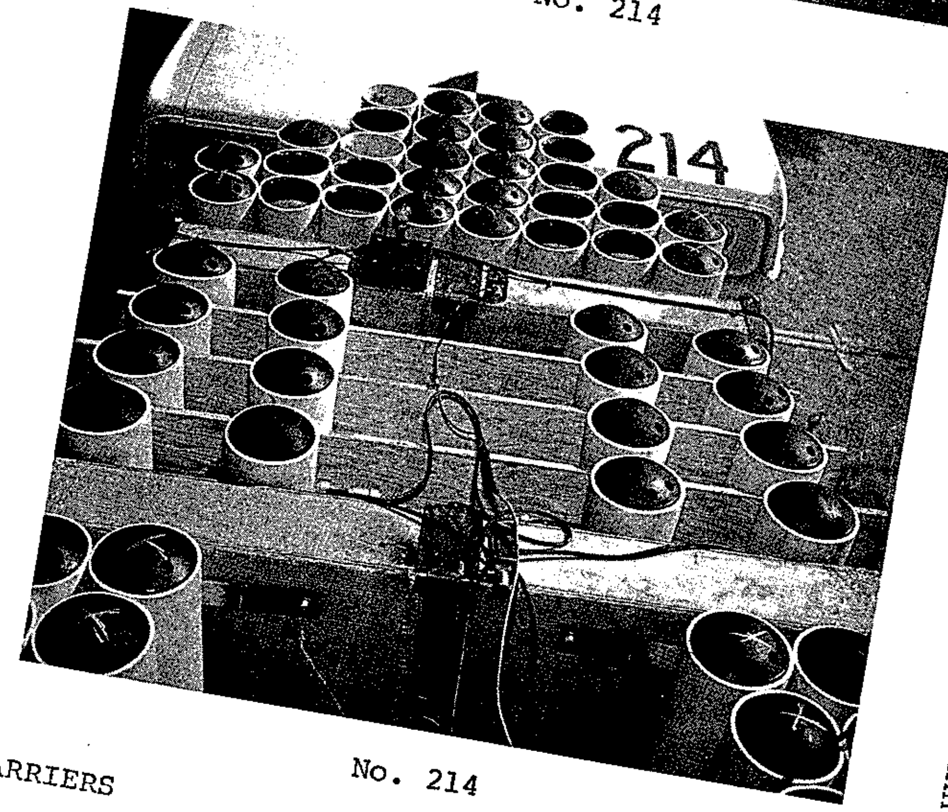
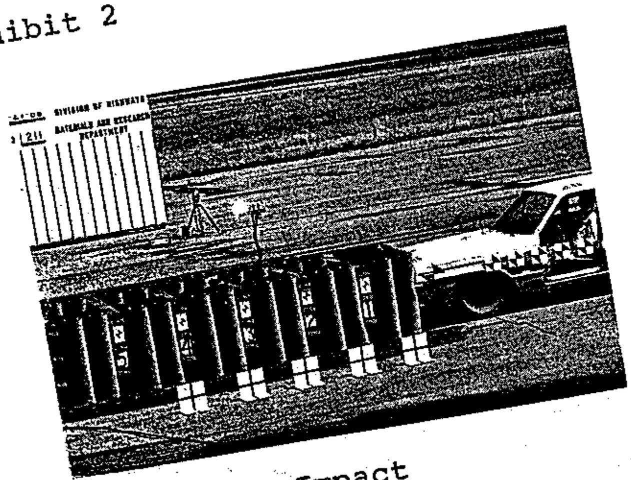


No. 214

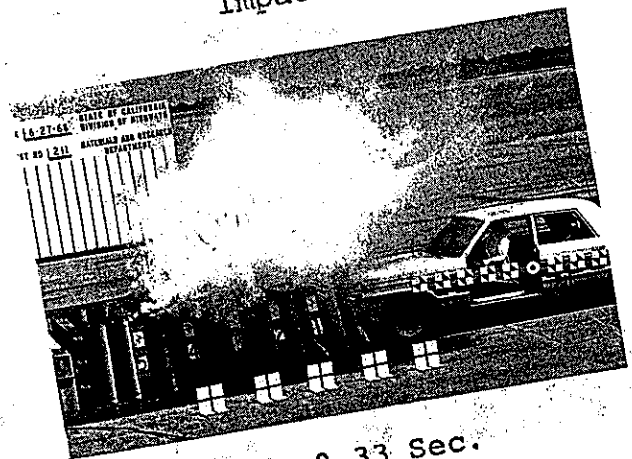
TEST BARRIERS

Exhibit 2

TEST 211



Impact



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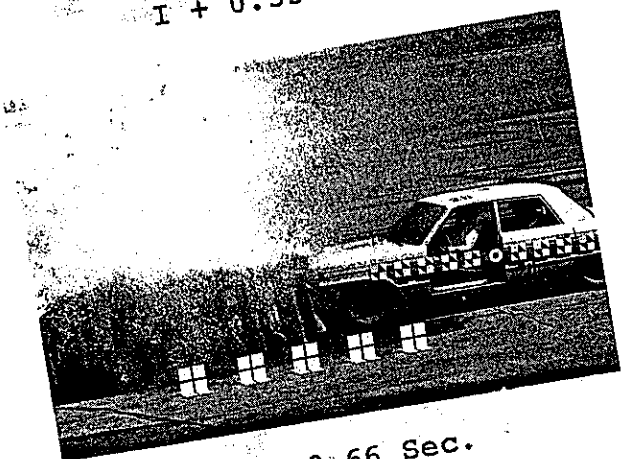

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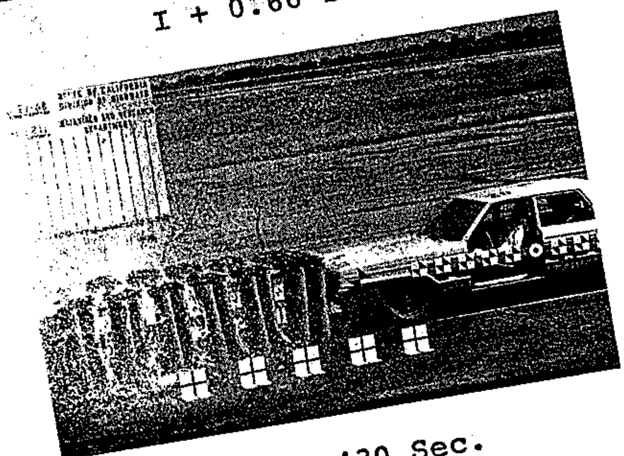
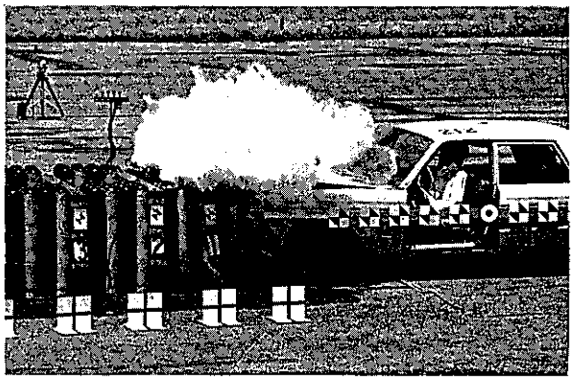


I + 1.430 Sec.

Test No.	211
Date	6-27-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy & Instrumentation	4680 Lbs.
Impact Speed	14.7 mph
Impact Angle	Head-on
Dummy Restraint	None

Barrier Depth	15'-0"
No. of Water Tubes	167
Vehicle Peak Deceleration	4 G's
Vehicle Average Deceleration (Highest 40 Ms)	3 G's
Permanent Displacement of Barrier Nose	4'-1"
Maximum Vehicular Penetration	5'-0"
Maximum Vehicular Rise	2"

TEST 212



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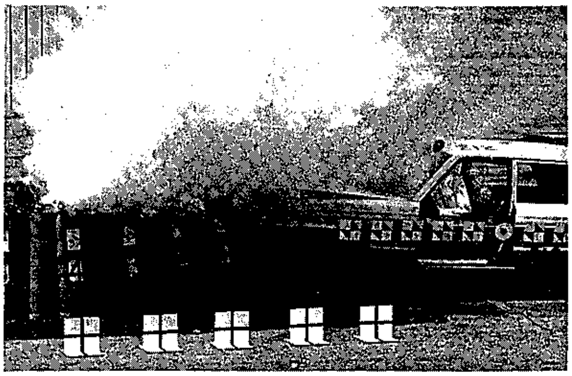

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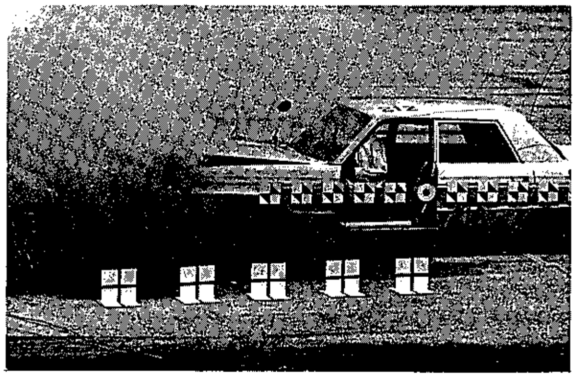
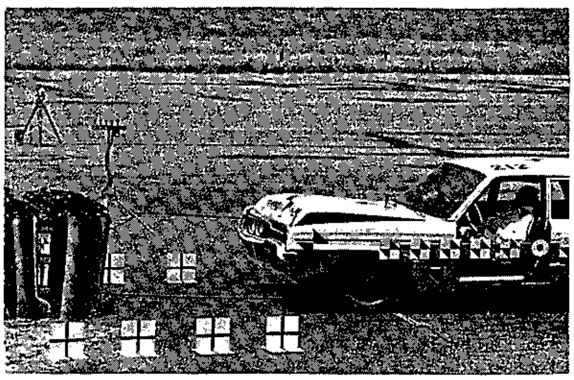


I + 0.55 Sec.



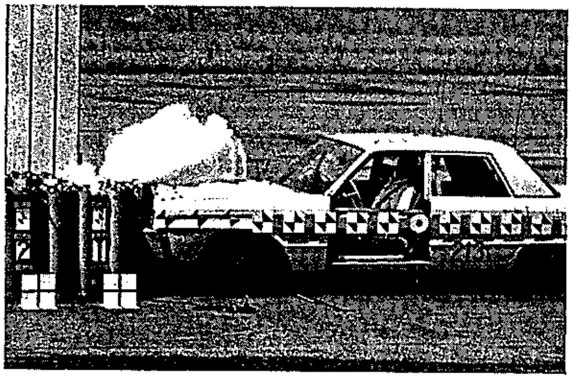
I + 2.58 Sec.

Test No.	212
Date	6-27-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy & Instrumentation)	4680 Lbs.
Impact Speed	33.3 mph
Impact Angle	Head-on
Dummy Restraint	None

Barrier Depth	15'-0"
No. of Water Tubes	167
Vehicle Peak Deceleration	18 G's
Vehicle Average Deceleration (Highest 40 Ms)	10 G's
Permanent Displacement of Barrier Nose	6'-6"
Maximum Vehicular Penetration	8'-4"
Maximum Vehicular Rise	9"

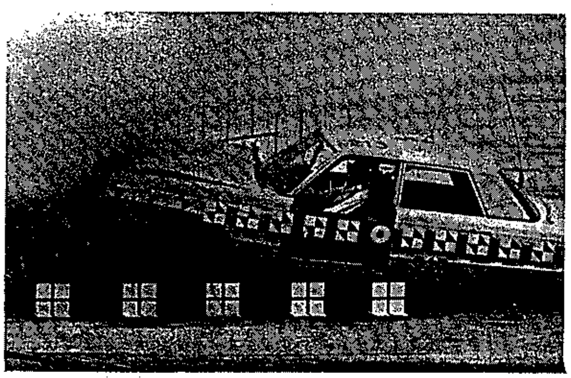
Exhibit 4

TEST 213

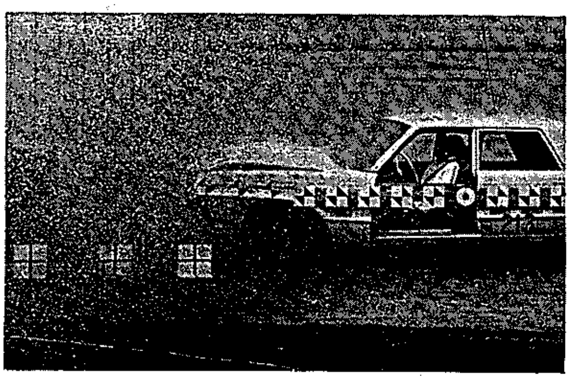


Impact + 0.03 Sec.

I + 0.12 Sec.



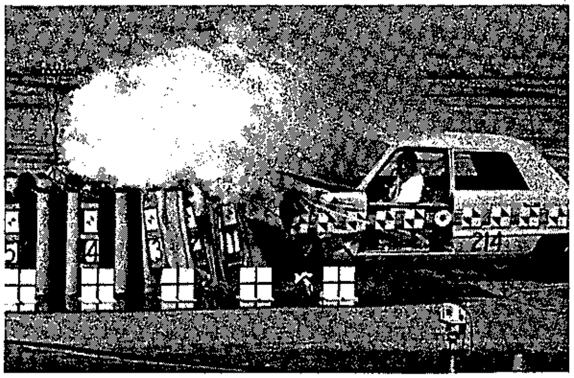
I + 0.39 Sec.



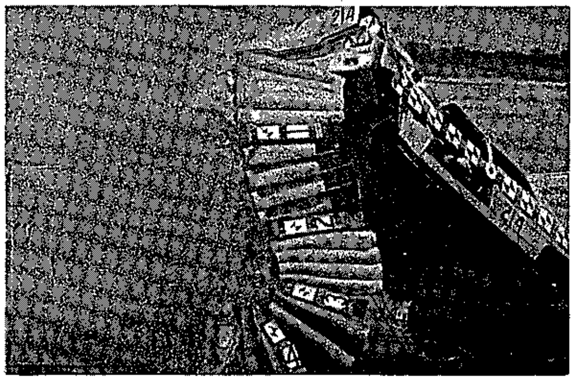
I + 1.99 Sec.

Test No.	213
Date	8-8-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy & Instrumentation)	4600 Lbs.
Impact Speed	48.2 mph
Impact Angle	Head-on
Dummy Restraint	Lap Belt & Single Shoulder Harness

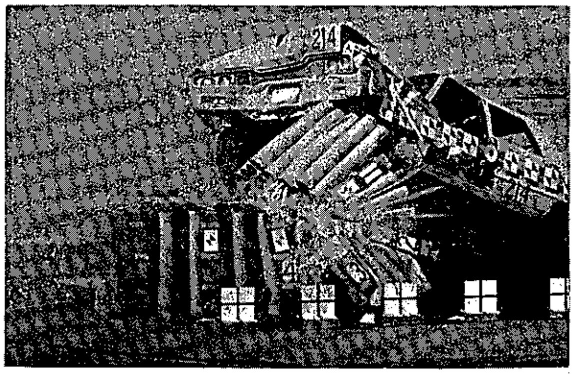
Barrier Depth	16'-5"
No. of Water Tubes	165
Vehicle Peak Deceleration	15 G's
Vehicle Average Deceleration (Highest 40 Ms)	11 G's
Permanent Displacement of Barrier Nose	6'-2"
Maximum Vehicular Penetration	12'-5"
Maximum Vehicular Rise	11"



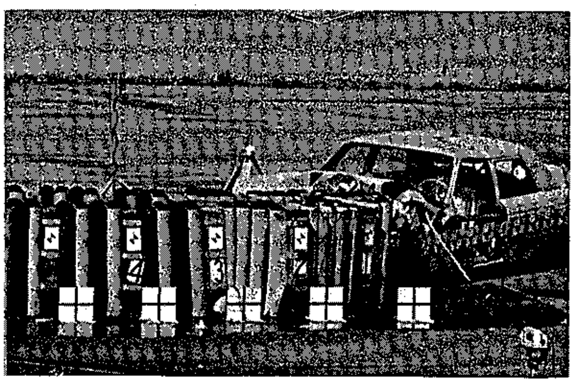
Impact + 0.08 Sec.



I + 0.93 Sec.



I + 1.45 Sec.

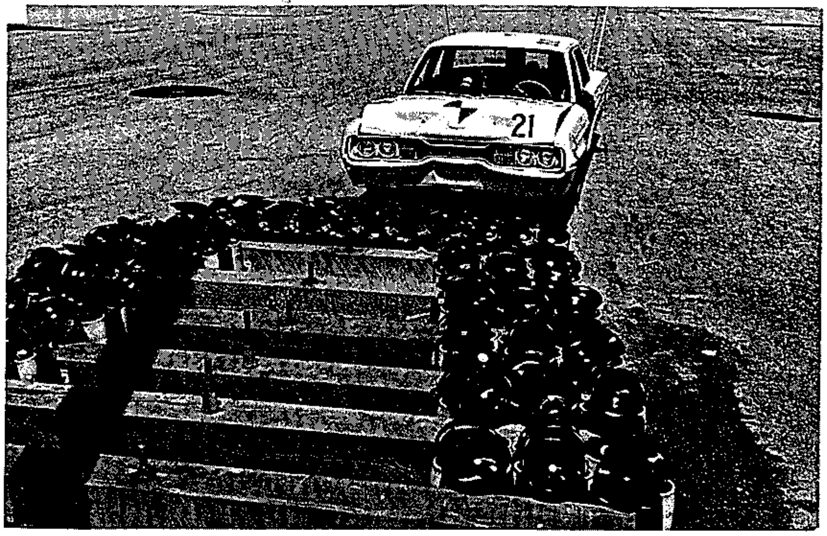


I + 3.66 Sec.

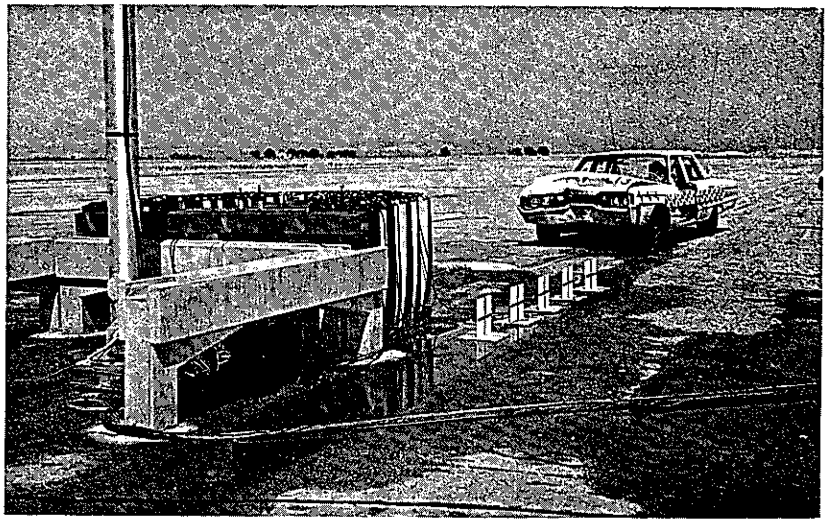
Barrier Depth	16'-2"
No. of Water Tubes	150
Vehicle Peak Deceleration	15 G's
Vehicle Average Deceleration (Highest 40 Ms)	10 G's
Permanent Displacement of Barrier Nose	3'-2"
Maximum Vehicular Penetration	13'-8"
Maximum Vehicular Rise	6'-2"

Test No.	214
Date	9-25-68
Vehicle	1966 Dodge
Vehicle Weight (W/Dummy & Instrumentation)	4600 Lbs.
Impact Speed	59.8 mph
Impact Angle	Head-on
Dummy Restraint	Lap Belt & Single Shoulder Harness

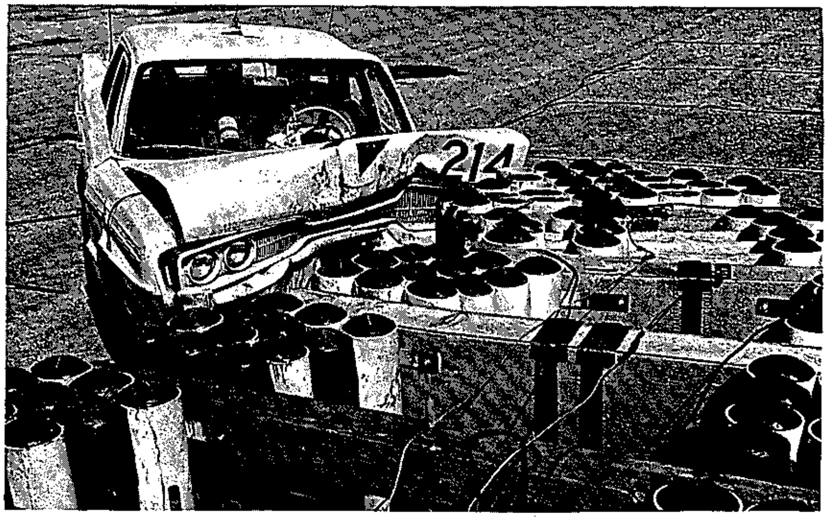
Exhibit 6



NO. 212

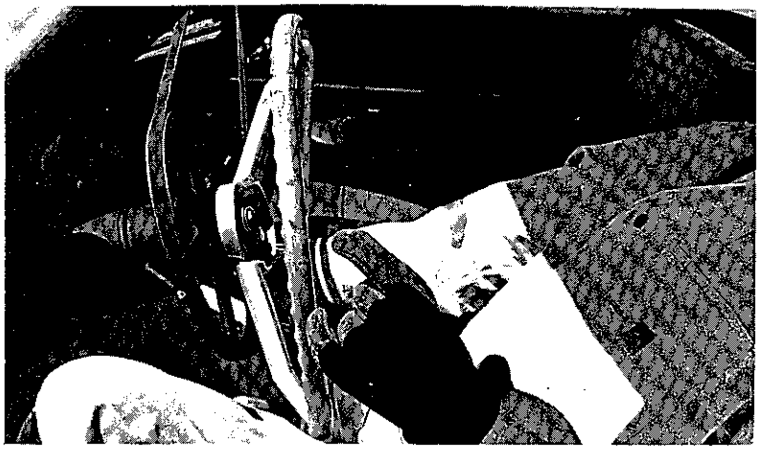


NO. 213

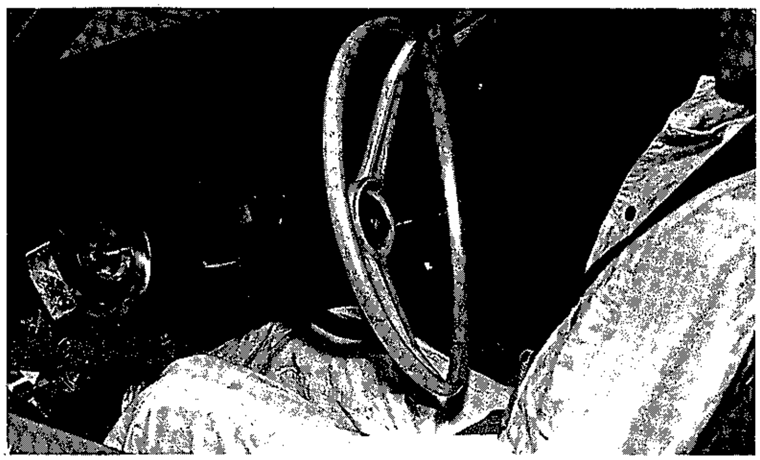


NO. 214

BARRIER AND VEHICLE DAMAGE



No. 212
2-1/4" Permanent Deformation



No. 213
2-1/2" Permanent Deformation

No. 214
3-3/4" Permanent Deformation

DEFORMATION OF STEERING WHEEL